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WEIGHT FLOW RATES THROUGH CIRCULAR HOLES IN A FLAT PLATE IMMERSED IN A SUBSONIC OR SUPERSONIC AIRSTREAM

8 August 1963

NOL

UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

NOLTR 61-125

NOLTR 61-125

Aerodynamics Research Report 162

WEIGHT FLOW RATES THROUGH CIRCULAR HOLES IN A FLAT PLATE IMMERSED IN A SUBSONIC OR SUPERSONIC AIRSTREAM

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ABSTRACT: This report presents the results of an investigation conducted in the Naval Ordnance Laboratory's Supersonic Tunnel No. 2 to measure the weight flow of air through various sized holes in a flat plate exposed to a flow parallel to the plane of the plate. These data were obtained at free-stream Mach numbers of 0.50 and 1.53 for various static pressure ratios across the flat plate.

Published January 1964
U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

WEIGHT FLOW RATES THROUGH CIRCULAR HOLES IN A FLAT PLATE IMMERSED IN A SUBSONIC OR SUPERSONIC AIRSTREAM

The purpose of this investigation was to obtain data on the weight flow rate of air through various sized holes in a flat plate exposed to a flow parallel to the plane of the plate. These tests were performed at the request of the General Electric Company under Task Number NOL 569. This research was supported by the Advanced Research Projects Agency, Ballistic Missile Defense Systems Branch, and was monitored by the U. S. Naval Research Laboratory (Code 6240) under Contract No. 173-6162-61.

R. E. ODENING
Captain, USN
Commander

K. R. Enkenhus

K. R. ENKENHUS
By direction

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ILLUSTRATIONS

REFERENCE

(1) Dittrick, R.T., and Graves, C.C., "Discharge Coefficients for Combustor-Liner Air-Entry Holes: 1-Circular Holes with Parallel Flow," NACA TN-3663, Apr 1956 Unclassified

INTRODUCTION

The investigation described was proposed by the General Electric Company to determine the flow through pierced plates exposed to a flow of air parallel to the plane of the plate. The data sought were the weight flow rate, and flow direction through the hole.

To obtain these data both transient and steady-state flow methods were proposed to provide a means of cross-checking test data. Due to complications, to be mentioned later, only the steady-state method gave reliable results.

SYMBOLS

A_h	cross-sectional area of hole in test box (ft^2)
C	flow discharge coefficient, W_{hs}/W_{th}
d	diameter of hole in test box (in)
g	gravity constant, 32.174 $(\frac{ft}{sec^2})$
k	ratio of specific heats for air, 1.4
M	free-stream Mach number
M_{th}	theoretical Mach number of flow through test box hole
P_n	pressure at position n, $(\frac{lbf}{ft^2})$ (see Figure 4 for values of n)
P_o	total pressure in wind tunnel test section
R	gas constant equals 53.3 $(\frac{ft\text{-}lbf}{lbm\,^\circ R})$
T	temperature, ($^\circ$R) unless otherwise noted
T_o	total temperature in wind tunnel test section, ($^\circ$R) unless otherwise noted
t	thickness of flat plate wall at hole (in)
U	free-stream velocity (ft/sec)

V	internal volume of test box (ft^3)
W_{hs}	measured weight flow rate of air through test box hole, steady state (lbm/sec)
W_{hi}	measured weight flow rate of air through test box hole, transient state (lbm/sec)
W_{th}	theoretical weight flow rate of air through test box hole (lbm/sec)
τ	time (sec)

EQUIPMENT, TEST TECHNIQUES AND DATA REDUCTION

Equipment

Photographs of the test box and flat plate mounted in the wind tunnel test section are shown in Figures 1A and 1B. A drawing of the test box is shown in Figure 2. Pressures were measured at the numbered locations shown on the drawing, and temperatures at the lettered locations. Details of the insert plate located in the flat plate (at the bottom of the test box) are shown in Figure 3. Although an attempt was made to measure the flow direction angle (β) by the use of a single tuft located at the center of the hole, no reliable data were obtained due to the violent fluctuations of the tuft. A layout of the overall instrumentation for the test is shown in Figure 4.

Steady-State Method

The principal method of obtaining weight flow rate data was the steady-state method. With valve 1 open, as shown in Figure 1A, and flow established in the wind tunnel test section, the pressure in the test box was reduced to below the test section static pressure by use of the vacuum sph e "pump" shown in Figure 4. When steady-state flow conditions were obtained, the flow rate of air entering the test box through the hole in the insert plate was measured with a nozzle flow-meter (Bailey Flowmeter). Measurements were made for various static pressure ratios across the plate.

Transient Method

The second method used to obtain weight flow rate data was the transient method. With valve 1 closed, as shown in Figure 1B, and flow established in the wind tunnel test section, the test box was pumped down with the fore-pump shown in Figure 4. Valve 1 was then opened and the temperatures and pressures in the test box were measured as a function of time

with thermocouples A through J and pressure transducers 1 through 10 (see Figures 2 and 4).

The temperature and pressure were plotted as a function of time for use in computing the transient state measured weight flow rate, W_{hi}. W_{hi} was determined from the relation

$$W_{hi} = \frac{V}{RT} \frac{\Delta P_1}{\Delta \tau} \tag{1}$$

where V, the volume of the test box, is equal to 1.88 cubic feet. The temperature, T, within the box was taken as a constant, since it was observed to vary little with time, and any variation was attributed to thermocouple lag and heat conduction. The quantity $\Delta P_1/\Delta \tau$ represents the slope of the pressure vs time plot taken at different intervals of time up to the point where the test box static pressure, P_1, equals the tunnel static pressure, P_{11}.

Transient vs Steady-State Methods

As shown in Figure 5, the values of weight flow rate obtained by the transient method were considerably higher than those obtained by the steady-state method. It is felt that the transient weight flow rate values are high due to the sluggish operation of valve 1, instrumentation lag and inaccuracies in the temperature measurements. The test box was not thermally insulated, and consequently it was subjected to some heat conduction during the time required to complete one set of measurements.

For the specific case shown in Figure 5, the maximum temperature recorded at thermocouple location "G" was used in the computation of the transient weight flow rates by equation (1). This temperature most closely represented the stagnation temperature of the incoming air. Undoubtedly better agreement between the transient and steady-state methods could be obtained by the use of an insulated test box and a quick-opening valve (valve 1).

Due to the inaccuracies of the transient method, the principal results presented were obtained by the steady-state method.

Flow Discharge Coefficient

In order to analyze the steady-state weight flow results in this test, the data were reduced to a non-dimensional form. The flow discharge coefficient (C) was calculated as the ratio of the measured flow rate to the theoretical flow rate, W_{hs}/W_{th}. The theoretical flow rate was calculated from the following isentropic compressible flow relationships:

$$W_{th} = \left\{ A_h P_{11} \, (k\ g)^{1/2} M_{th} \right\} / \left\{ (R\ T_o)^{1/2} \left(1 + \frac{k-1}{2} M_{th}{}^2\right)^{\frac{k+1}{2(k-1)}} \right\} \tag{2}$$

where $M_{th} = \sqrt{2 \left[(P_{11}/P_{14})^{\frac{k-1}{k}} - 1 \right] / (k-1)}$ for $P_{14}/P_{11} > 0.5283$

and $M_{th} = 1$ for $P_{14}/P_{11} \leq 0.5283$

P_{11}, the static pressure in the wind tunnel, is measured on the flat plate upstream of the hole and it is assumed to be the total pressure through the hole. P_{14} is the static pressure measured inside the box and it is equal to P_1.

RESULTS AND DISCUSSION

A plot of the measured weight flow rate vs the static pressure ratio (P_{14}/P_{11}) is presented in Figure 6. As can be seen from this figure, the predominant factors influencing the measured weight flow rate are the parallel flow Mach number, hole diameter and hole thickness. The weight flow rate increases as the Mach number decreases since as the Mach number diminishes the free-stream static pressure increases. The diameter of the hole has a larger effect on the weight flow than does the hole thickness. It is obvious that for the same conditions as the diameter of the hole increases the weight flow rate through the hole will also increase. However, the fact that the weight flow rate is slightly higher for the thicker of two holes of equal diameter and pressure ratio at the same parallel flow Mach number is less obvious, and the cause of this has not yet been resolved.

Figure 7 (C vs P_{14}/P_{11}) shows that hole thickness to diameter ratio has a small effect on flow discharge coefficient.

More important is the effect of the parallel flow Mach number. The curve from reference (1), for the case of zero parallel flow velocity, provides an upper bound for values of the flow discharge coefficient. Factors such as wind tunnel test section height, boundary-layer thickness and test section static pressure level were examined in reference (1) and found to have a negligible effect on the discharge coefficient.

The variation of the flow discharge coefficient with the flow parameter at various parallel flow Mach numbers is shown in Figure 8. The flow parameter is the ratio of the pressure difference across the hole to the pressure difference across the wind tunnel nozzle. The data from reference (1) compare favorably with the present data, and illustrate the effect of the parallel flow Mach number (or velocity) on the flow discharge coefficient. For the flow parameter equal to a constant we note that the discharge coefficient increases as the parallel flow Mach number increases.

CONCLUDING REMARKS

For the range of parameters investigated in this study, the following conclusions may be drawn:

1. The measured weight flow rate decreases as the parallel flow Mach number increases.

2. Increasing the parallel flow velocity from zero to supersonic may more than halve the flow discharge coefficient for a given pressure ratio across the hole.

3. The effect of the parallel flow Mach number on the flow discharge coefficient is much greater than the effect of the hole thickness to diameter ratio for $t/d < 1$.

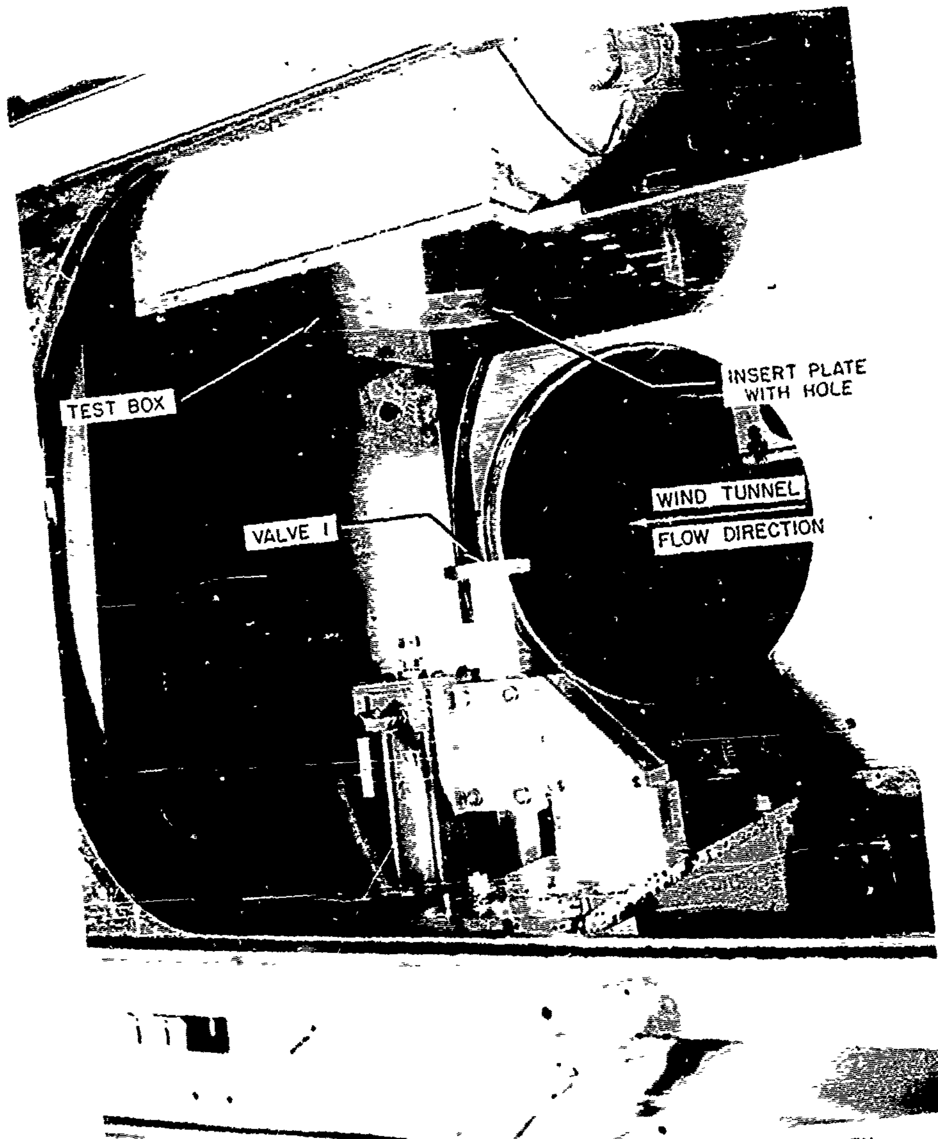

FIG IA TEST BOX MOUNTED IN WIND TUNNEL WITH VALVE I OPEN

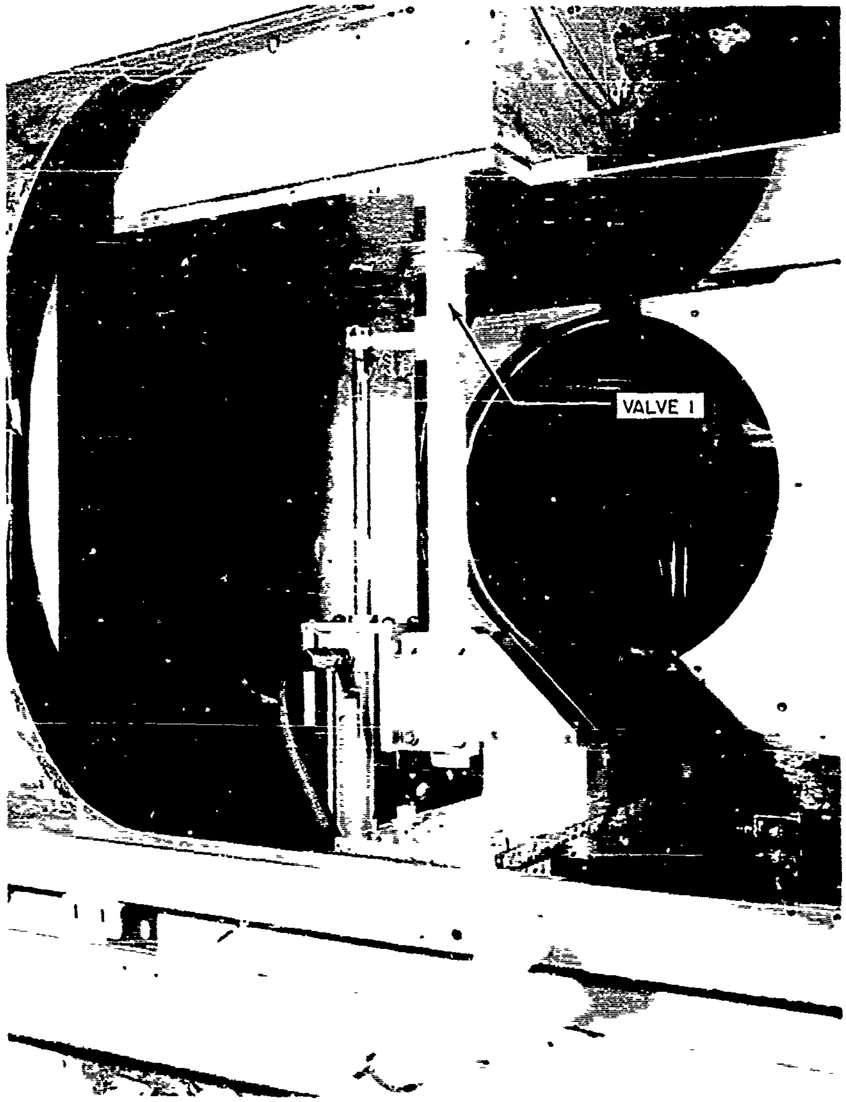

FIG 1B TEST BOX MOUNTED IN WIND TUNNEL WITH VALVE 1 CLOSED

NOTES: 1. ALL DIMENSIONS IN INCHES
2. DIMENSIONS REFERENCED TO OUTSIDE OF BOX. BOX WALLS A[illegible] 1/2" THICK.

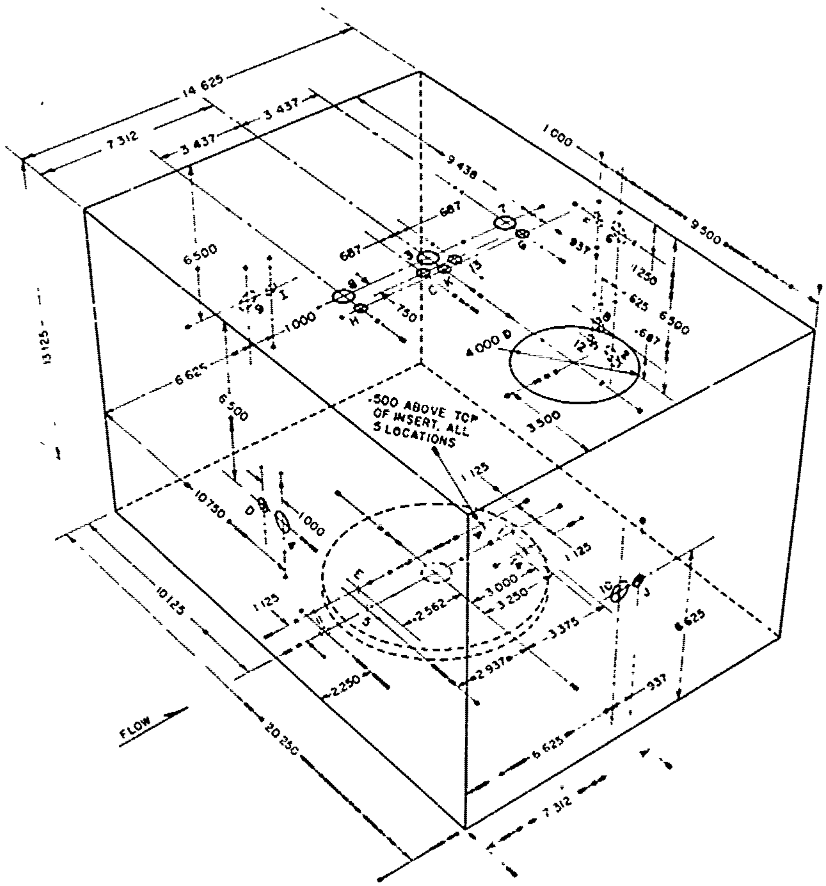

FIG. 2 PIERCED WALL TEST BOX

NOTES: 1. ALL DIMENSIONS IN INCHES
2. DIMENSIONS REFERENCED TO OUTSIDE OF BOX. BOX WALLS ARE 1/2" THICK.

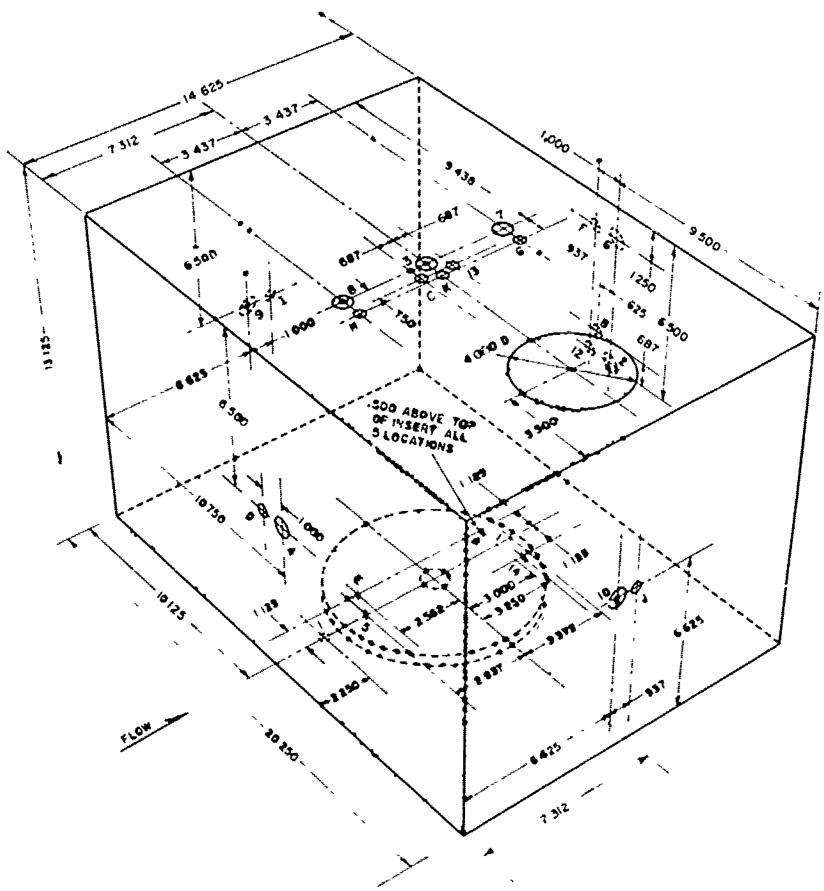

FIG. 2 PIERCED WALL TEST BOX

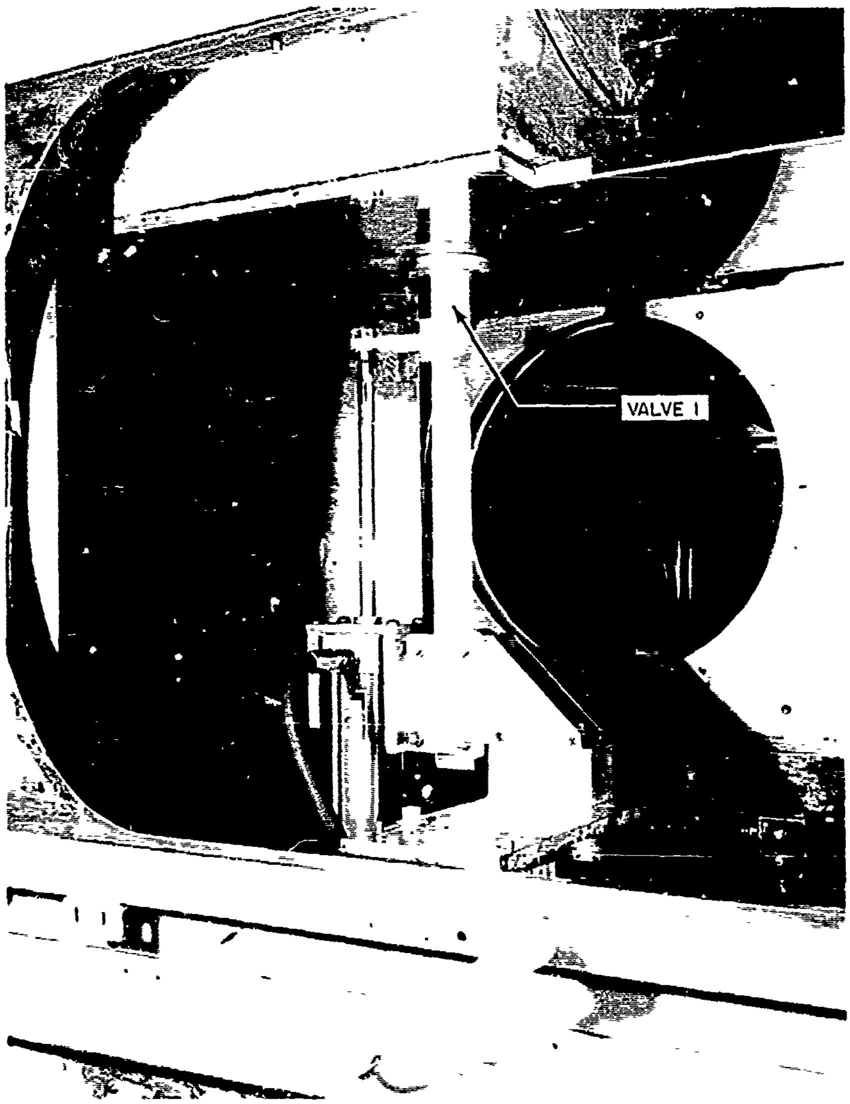

FIG 1B TEST BOX MOUNTED IN WIND TUNNEL WITH VALVE 1 CLOSED

d (in)	t (in)
0.50	0.10
1 00	0 10
1 00	0 20
1 00	0.50
1.00	1 00
2.00	0 40
2.00	2.00
2.00	3.00

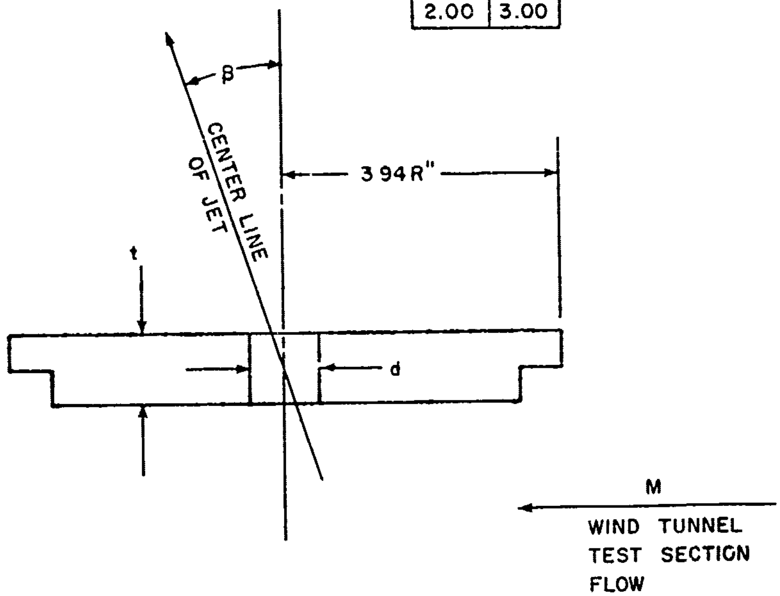

FIG. 3 INSERT PLATE FOR PIERCED WALL TEST BOX

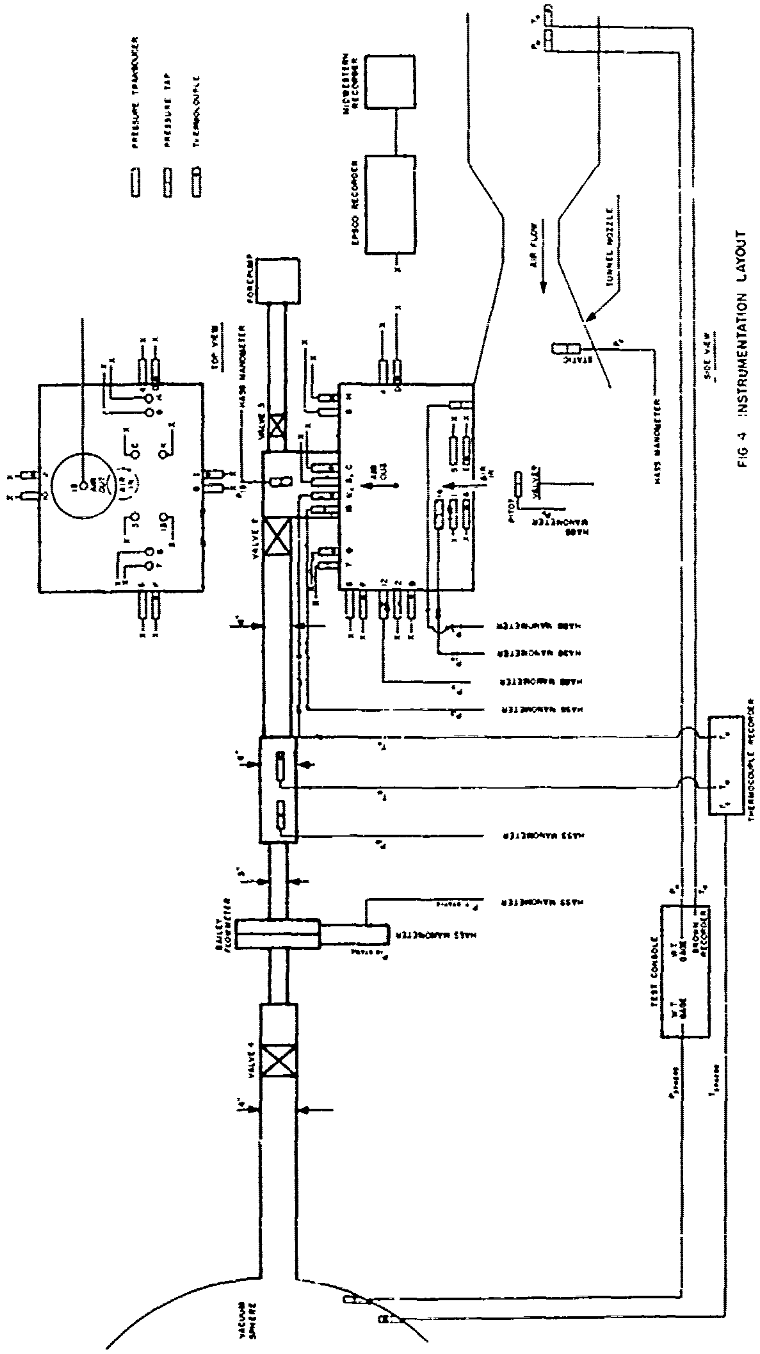

FIG 4 INSTRUMENTATION LAYOUT

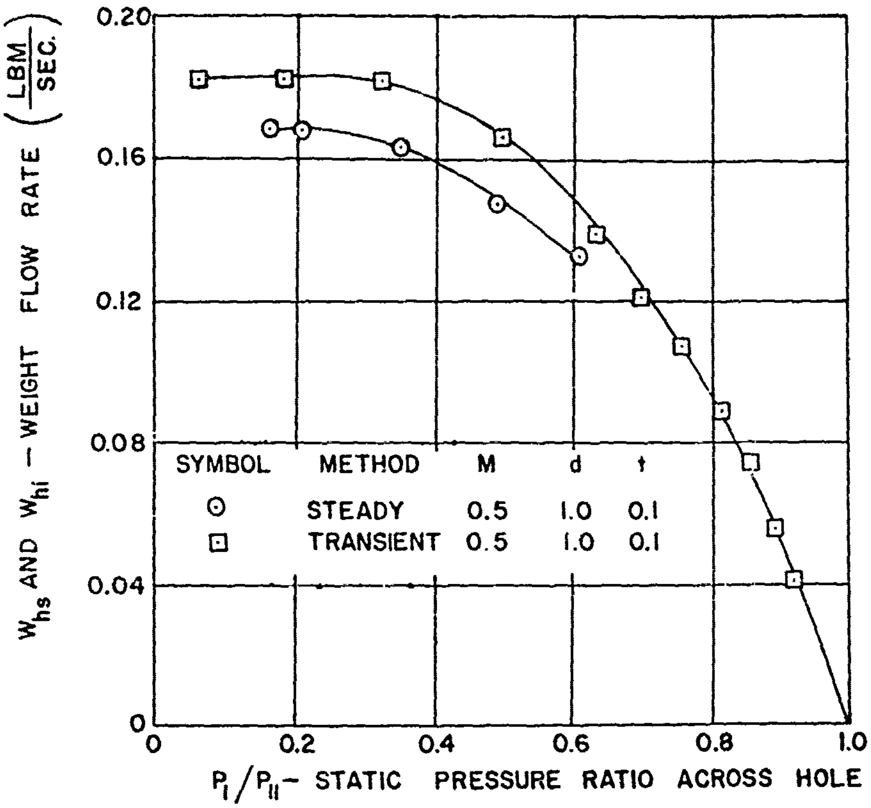

FIG. 5 COMPARISON OF WEIGHT FLOW RATES OBTAINED BY STEADY STATE AND TRANSIENT METHODS.

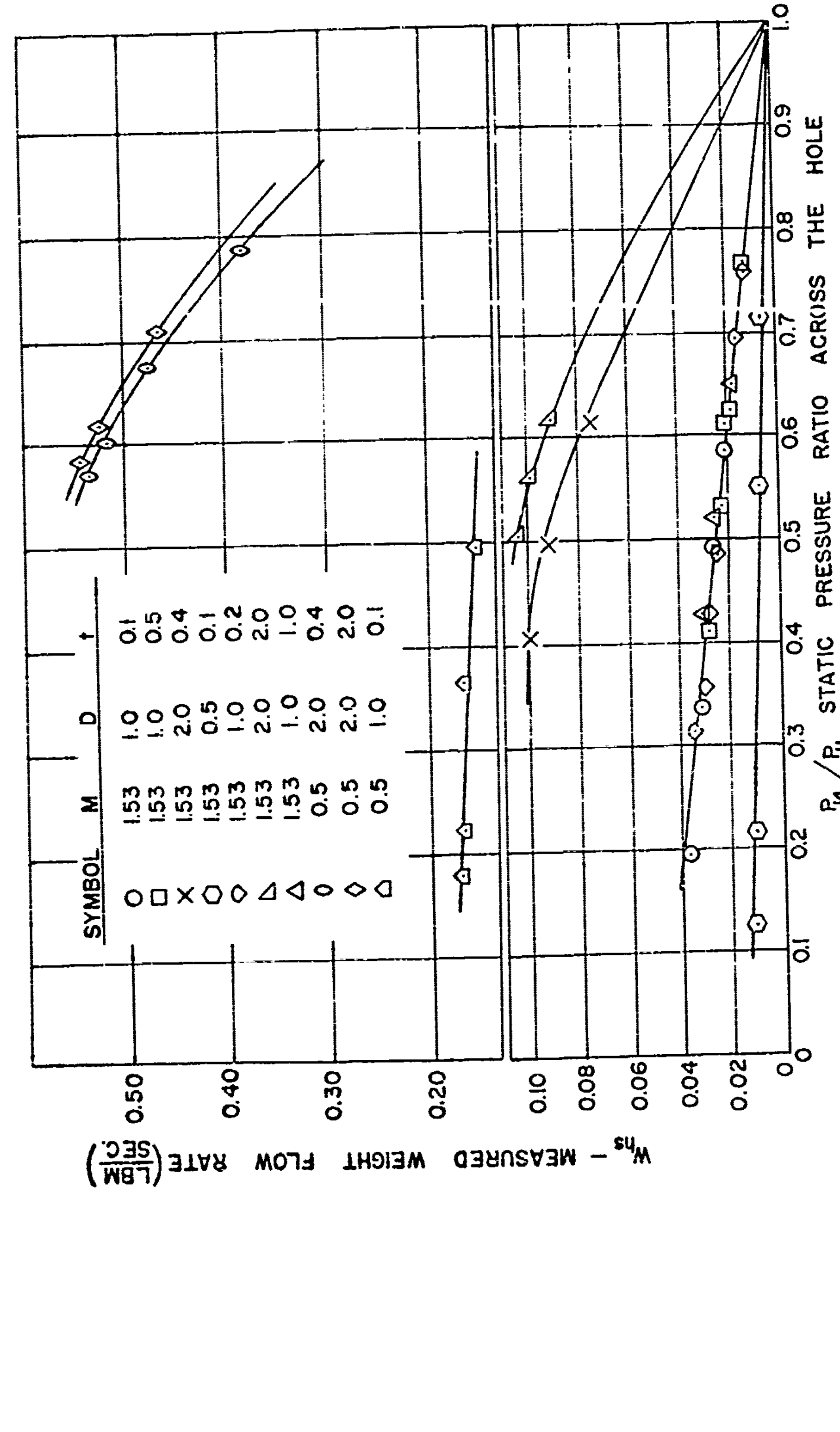

FIG. 6 MEASURED WEIGHT FLOW RATE VS. STATIC PRESSURE RATIO

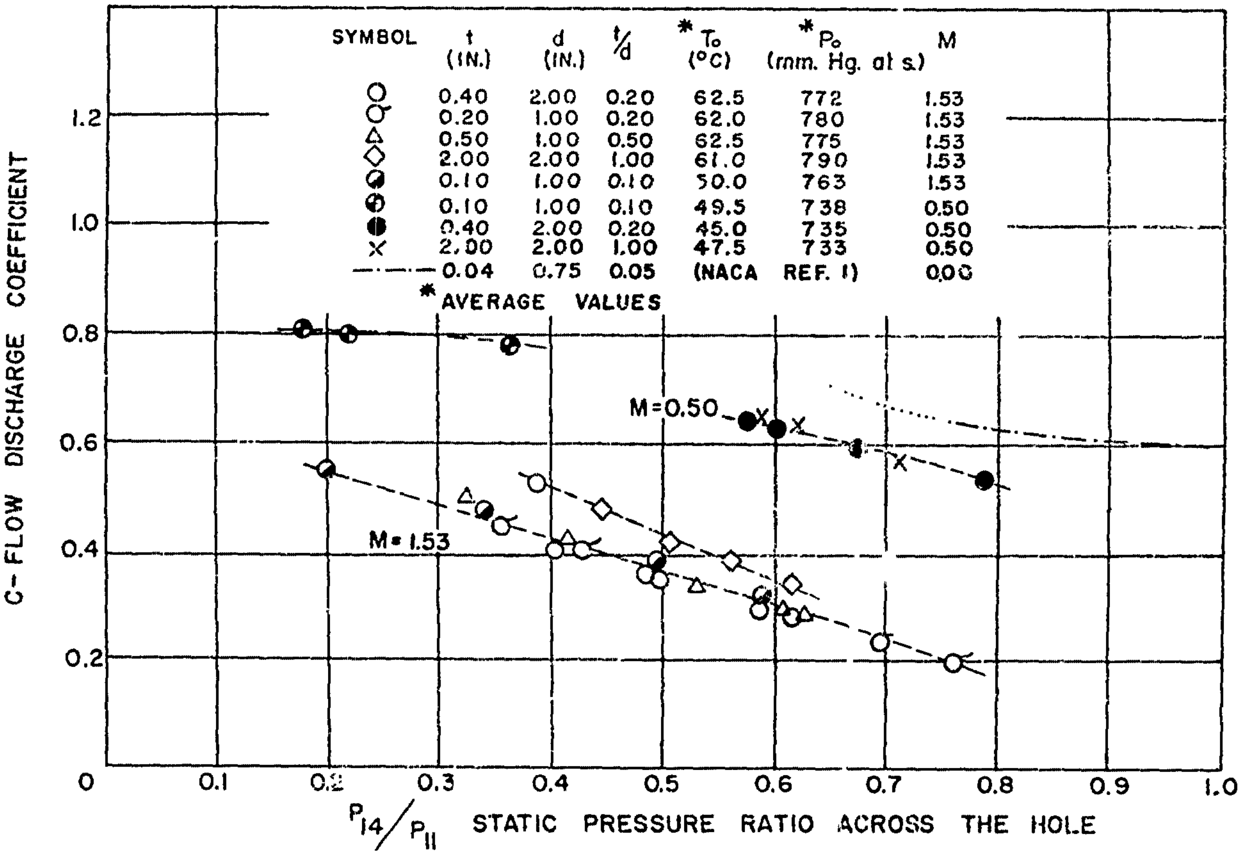

FIG. 7 FLOW DISCHARGE COEFFICIENT VS. STATIC PRESSURE RATIO FOR VARIOUS PARALLEL FLOW MACH NUMBERS

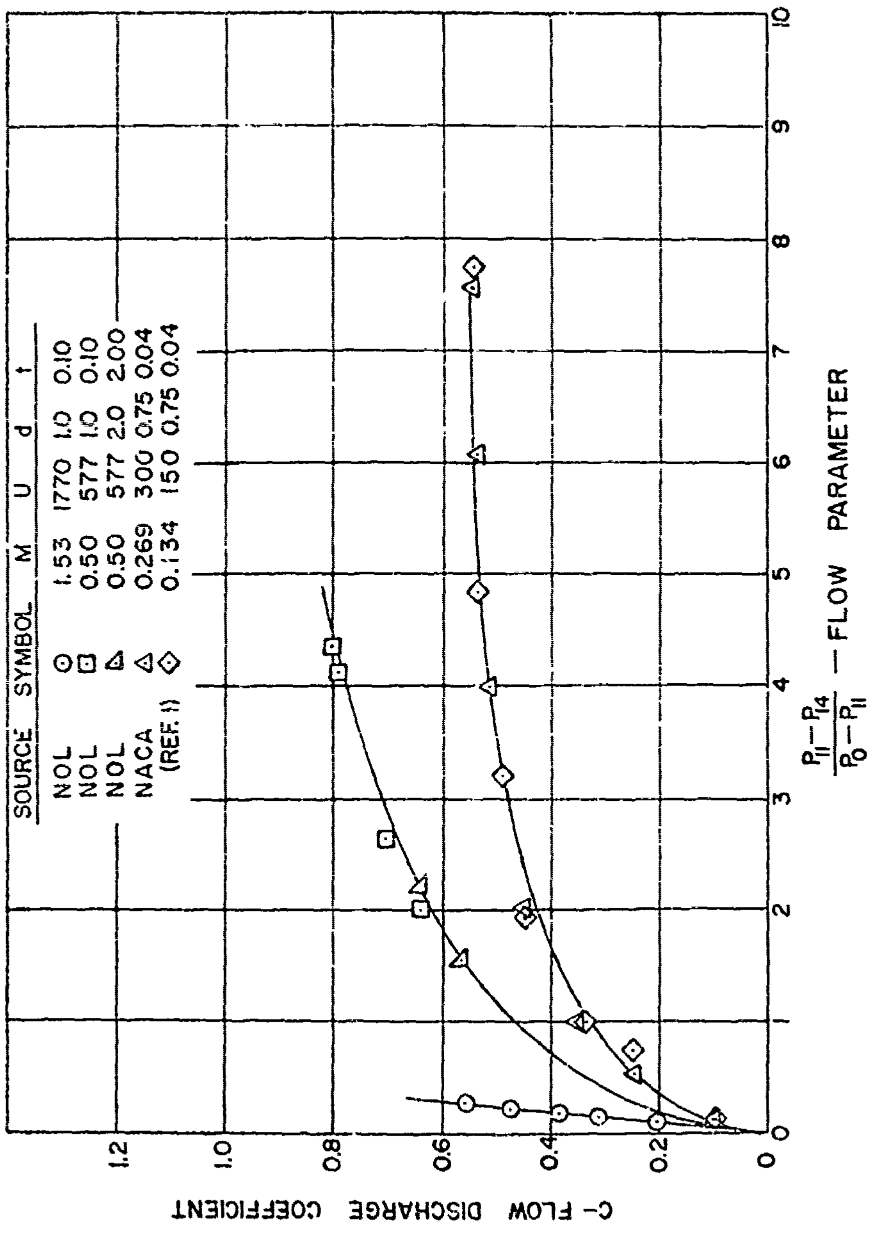

FIG. 8 EFFECT OF CROSSFLOW VELOCITY ON THE FLOW DISCHARGE COEFFICIENT FOR VARIOUS VALUES OF FLOW PARAMETER

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